INTERACTIONS IN MULTIPLE SCHEDULES: NEGATIVE INDUCTION WITH SQUIRREL MONKEYS[1]

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In Experiment I, lever pressing by squirrel monkeys was maintained under a sequence of variable-interval, multiple variable-interval variable-interval, and multiple variable-interval extinction schedules of food presentation. Negative induction (decreased responding in the unchanged component) occurred when one component of the multiple variable-interval variable-interval schedule was changed to extinction. Negative induction was transient over sessions; responding in the unchanged component usually recovered to a rate similar to that under the multiple variable-interval variable-interval schedule. Negative induction was not accompanied by consistent changes in the patterns of local responding within the unchanged component, and did not depend on whether component schedules were associated with localized (lever lights) or diffuse visual stimuli (houselights), or on whether the unchanged component was a 60- or 180-sec variable-interval schedule. In Experiment II, responding was maintained under a sequence of variable-interval and multiple variable-interval timeout schedules of food presentation. Negative induction occurred when responding declined gradually in the timeout component but not when responding declined abruptly. The nature of interactions in multiple schedules may depend on the species; negative induction was observed with squirrel monkeys under conditions similar to those that produce positive contrast with pigeons.

Key words: negative induction, multiple-schedule interactions, discriminative stimulus location, lever lights, houselights, multiple schedules, variable-interval schedules, lever press, squirrel monkeys

When one component of a multiple variable-interval variable-interval (*mult* VI VI) schedule is changed to extinction (EXT), the rate of responding in the unchanged component may increase concomitantly with a rate decrease in the changed component. This effect, called positive behavioral contrast (Reynolds, 1961), has been observed reliably when key pecking by pigeons produced food and when stimuli associated with components of the multiple schedule were localized on the response key (*cf.* Schwartz and Gamzu, 1977). Contrast usually has not been observed with pigeons under other conditions. When treadle pressing rather than key pecking produced food, contrast did not develop

(Hemmes, 1973; Westbrook, 1973). When components of the multiple schedule were associated with diffuse stimuli (houselights, tones) or stimuli localized away from the key, contrast either did not occur (Keller, 1974; Redford and Perkins, 1974; Schwartz, 1975; Schwartz, Hamilton, and Silberberg, 1975; Spealman, 1976) or occurred with reduced magnitude (Westbrook, 1973; but see Hemmes, 1973).

With species other than pigeons, attempts to demonstrate contrast under multiple schedules of food presentation have produced inconsistent results. When lever pressing by rats produced food and when components were associated with diffuse stimuli, contrast was observed with some, but not all subjects (*e.g.*, Beninger and Kendall, 1975; Gutman, Sutterer, and Brush, 1975; Pear and Wilkie, 1971; White, 1978). Indeed, negative induction (decreased responding in the unchanged component) often has been reported as more common (*e.g.*, Freeman, 1971; Zimmerman and Schuster, 1962). Similarly, there has been no unequivocal demonstration of contrast under multiple schedules of food presentation with

primates. Ferster (1958, Experiment 2) reported that the rate of lever pressing by chimpanzees increased when a VI schedule of food presentation was interrupted periodically by timeouts. This effect cannot be interpreted unambiguously as contrast, however, since timeouts were response-produced, and Ferster (Experiment 5) also observed decreased responding when responses produced timeouts. Moody, Stebbins, and Iglauer (1971) found no evidence for a latency contrast effect (cf. Jenkins, 1961; Terrace, 1963) under a trial procedure in which lever-releasing responses by rhesus monkeys produced food in the presence of one but not another tone.

Results such as these have prompted some (e.g., Blough, 1972) to question the generality of positive contrast. Others (e.g., Hearst and Jenkins, 1973; Rachlin, 1973; Schwartz and Gamzu, 1977) have stressed that such results are consistent with an "additivity" account of contrast. According to this view, positive contrast is expected only when responding that is maintained by a contingency between stimulus and reinforcer is also directed to the manipulandum on which responses produce food. For example, when the stimuli associated with components of a mult VI EXT schedule are localized on the response key, key pecking by pigeons is maintained not only by the contingency between key pecks and food presentation (the response-reinforcer contingency) but also by the contingency between keylight and food presentation (the stimulus-reinforcer contingency). Under an equal-valued mult VI VI schedule, however, key pecking is maintained only by the extant response-reinforcer contingency; no stimulus-reinforcer contingency exists because food presentations occur equally often in the presence of each keylight stimulus. Hence, responding in the unchanged component increases when a mult VI VI schedule is changed to mult VI EXT (positive contrast) but only when manipulandum-directed responses (key pecks) are maintained by both response-reinforcer and stimulus-reinforcer contingencies. When the latter contingency does not maintain manipulandum-directed responses, as when pecks are directed to a stimulus located elsewhere (e.g., Keller, 1974) or when pecks are not clearly directed to a diffuse stimulus (e.g., Redford and Perkins, 1974), positive contrast does not occur.

Based on this "additivity" account, the failure to obtain reliable positive contrast with rats and monkeys is not surprising; the stimuli associated with components of the multiple schedule were not localized on the manipulandum in experiments with these species. In such cases, the putative responding maintained by the stimulus-reinforcer contingency would not necessarily be expected to occur on the manipulandum. It is possible, however, that positive contrast occurs with nonavian species when the stimuli associated with component schedules are localized on the manipulandum. Experiment I investigated this possibility. Squirrel monkeys were exposed to a sequence of VI, mult VI VI, and mult VI EXT schedules in which visual stimuli associated with component schedules were either diffuse or localized on the response lever.

EXPERIMENT I

METHOD

Subjects

Four mature male squirrel monkeys (Saimiri sciureus), weighing 810 to 900 g when allowed free access to food and water, were maintained at about 80% of their free-feeding weights by restricting their access to Purina Monkey Chow after experimental sessions. Between sessions, monkeys were housed individually and had unlimited access to water. Monkey S-332 had been studied previously under a variable-interval schedule of electric shock presentation. Monkey S-500 had been studied under several schedules of food presentation and intravenous cocaine injection. Monkeys S-28 and S-146 were experimentally naive at the beginning of the study.

Apparatus

During sessions, each monkey sat in a primate restraining chair similar to that described by Hake and Azrin (1963). A response lever was made of transparent Plexiglas and had dimensions equal to those of a commercially available lever (BRS/LVE, model 121-05). The lever was mounted on a metal wall in front of the monkey, 8 cm above the waist plate and 8 cm from the right side wall of the chair. Operation of the lever by a minimal downward force of 0.20 N produced

an audible click of a relay mounted behind the front wall and was recorded as a response. In procedures involving lever lights, red and green lamps (6 W, 115 V ac) were mounted behind the Plexiglas lever, and were enclosed in a metal box to prevent stray light from illuminating the food tray or other features of the chamber. When lighted, these lamps transilluminated the lever (localized visual stimulus). In procedures involving houselights, red and green lamps were mounted behind the front wall, out of direct sight. When lighted, these lamps illuminated the entire chamber, but did not transilluminate the lever (diffuse visual stimulus). A food-pellet dispenser (Gerbrands, model D-1) could deliver 250-mg food pellets (Riddle, Rednick, Catania, and Tucker, 1966) to a tray accessible through a 4.5-cm by 4.5-cm aperture in the front wall. A white lamp (6 W, 115 V ac) illuminated the tray for 1 sec when the dispenser was operated. The chair was housed inside a sound-attenuating chamber furnished with a ventilation fan and white masking noise. Scheduling and recording equipment was located in another room.

Procedure

Monkeys S-28, S-146, and S-332 were first trained to retrieve and eat food pellets delivered independently of responding. Each of the first 60 lever-press responses then produced a pellet of food. Because of its experimental history, Monkey S-500 required no preliminary training. After preliminary training, each monkey was exposed to a variable-interval schedule of food presentation. For S-28 and S-332, responding produced food on the average of once every 180 sec (VI 180-sec) in the presence of the red lever light. For S-146 and S-500, responding produced food on the average of once every 60 sec (VI 60-sec) in the presence of the red lever light (S-146) or red houselight (S-500). Each VI schedule was made up of 15 different time intervals derived from a constant-probability distribution (Catania and Reynolds, 1968) and arranged in an irregular order. Sessions lasted 1 hr.

A second variable-interval schedule component was then introduced (*mult* VI VI). Responding produced food according to the VI 180-sec (S-28, S-332) or the VI 60-sec schedule (S-146, S-500) in each component. Components were associated with the red and green lever

lights (houselights for S-500) and alternated every 180 sec. Scheduled food presentations not produced by a response were cancelled following component change. Sessions began with the component associated with the red lever light or red houselight and ended after 10 presentations of each component (1 hr).

The schedule in the second component was then changed to extinction (*mult* VI EXT). Responding continued to produce food according to the VI 180-sec or VI 60-sec schedule in the presence of the red lever light or red houselight; responding never produced food in the presence of the green lever light or green houselight. The VI component lasted for 180 sec. The EXT component lasted for a minimum of 180 sec and until responding ceased for 10 sec. This "correction" procedure was used to minimize the possibility of adventitious maintenance of responding in the EXT component by subsequent presentations of the VI component (*cf.* Terrace, 1966*a*) and to maximize the possibility of obtaining a large positive contrast effect (peak contrast; *cf.* Bloomfield, 1966; Terrace, 1966*a*). Sessions ended after 10 presentations of each component (1 hr or longer, depending on responding in the EXT component). The *mult* VI VI schedule was then reinstated.

The entire sequence of schedules (VI, *mult* VI VI, *mult* VI EXT, *mult* VI VI) was repeated. In this second sequence, the stimuli (lever lights, houselights) associated with component schedules were changed for each monkey. For S-28, S-332, and S-146, components were associated with the red or green houselights; for S-500, components were associated with the red or green lever lights. Under each sequence, sessions were conducted five days per week. Table 1 shows the sequence of conditions and the number of sessions under each condition for individual monkeys.

Measurement of responding. Mean overall rates of responding were computed over the entire session under the VI schedule and in each component of the *mult* VI VI and *mult* VI EXT schedules. For analysis of local response patterning, components of the multiple schedules were divided into 10 successive segments. Each segment of the VI component was 18 sec. The first nine segments of the EXT component were also 18 sec; the last segment was 18 sec or longer, depending on responding. Responses in corresponding seg-

Table 1

Sequence of conditions and number of sessions under
each condition.

Monkey	Stimulus Light	Schedule		Number of Sessions
		Red	Green	
S-28	Lever	VI 180-sec	—[a]	27
			VI 180 sec	10
			EXT	30
			VI 180-sec	10
	House		—	10
			VI 180-sec	10
			EXT	28[b]
S-332	Lever	VI 180-sec	—	22
			VI 180-sec	10
			EXT	30
			VI 180-sec	10
	House		—	13
			VI 180-sec	10
			EXT	30
			VI 180-sec	10
S-146	Lever	VI 60-sec	—	21
			VI 60-sec	10
			EXT	30
			VI 60-sec	10
	House		—	12
			VI 60-sec	10
			EXT	30
			VI 60-sec	10
S-500	House	VI 60-sec	—	16
			VI 60-sec	10
			EXT	30
			VI 60-sec	10
	Lever		—	10
			VI 60-sec	10
			EXT	30
			VI 60-sec	10

[a]VI schedule in isolation.
[b]S-28 died after twenty-eighth session under this condition.

ments were accumulated over the entire session and mean local rates of responding were computed in each segment.

RESULTS AND DISCUSSION

Figures 1 and 2 show changes in the overall rate of responding in each component over the four conditions of the experiment for individual monkeys. Components were associated either with red and green lever lights (Figure 1) or with red and green houselights (Figure 2). When the VI schedule (panel 1) was changed to *mult* VI VI (panel 2), the rate of responding in each component of the *mult* VI VI schedule was similar to that under the VI schedule in isolation. When one component of the *mult* VI VI schedule was

changed to EXT (panel 3), responding initially declined in each component (negative induction). The occurrence of negative induction did not depend on whether components were associated with lever lights (Figure 1) or houselights (Figure 2), or on whether the unchanged component schedule was VI 180-sec (S-28, S-332) or VI 60-sec (S-146, S-500). With the exception of Monkey S-332, negative induction was transient over sessions; responding in the VI component usually recovered to a rate similar to that under the preceding *mult* VI VI schedule. Responding in the EXT component declined to a low rate. When the *mult* VI VI schedule was reinstated (panel 4), responding in each component was similar to that obtained previously under this schedule.

Figures 3 and 4 show changes in the mean local rate of responding (points) and ranges (vertical lines) within successive segments of each component during representative sessions under the *mult* VI VI, *mult* VI EXT, and subsequent *mult* VI VI schedules. Components were associated either with lever lights (Figure 3) or with houselights (Figure 4). During the last three sessions of the *mult* VI VI schedule (Sessions 18 to 20 in the figures), the local rate of responding varied unsystematically across successive segments of each component. When the *mult* VI EXT schedule was introduced *and* when overall negative induction was observed (Sessions 21 to 23 for S-500, lever light; Sessions 28 to 30 in all other cases), the local rate of responding declined during most segments of the VI component. In three of eight cases (S-146, lever light and houselight; S-500, houselight), the mean local rate of responding was lowest during initial segments of the VI component; in two other cases (S-500, lever light; S-332, houselight), the mean local rate of responding was highest during initial segments of that component. In all cases, however, within-component trends in mean local responding were small compared to the marked overlap in ranges. Thus, overall negative induction was not accompanied by consistent changes in patterns of local responding within the VI component. After continued exposure to the *mult* VI EXT schedule (Sessions 46 to 48 for S-28, houselight; Sessions 48 to 50 in all other cases), the local rate of responding recovered during most segments of the VI component for all
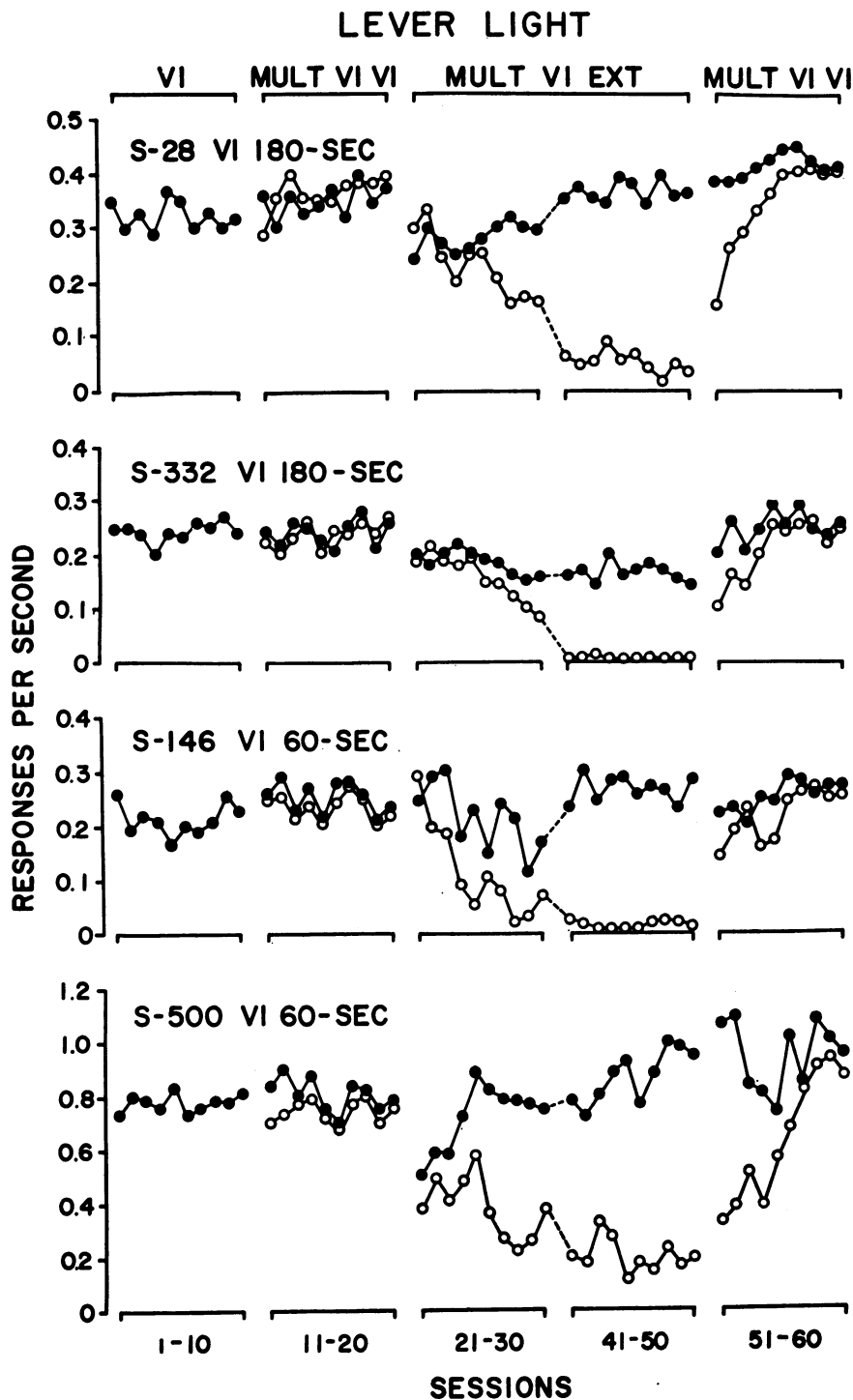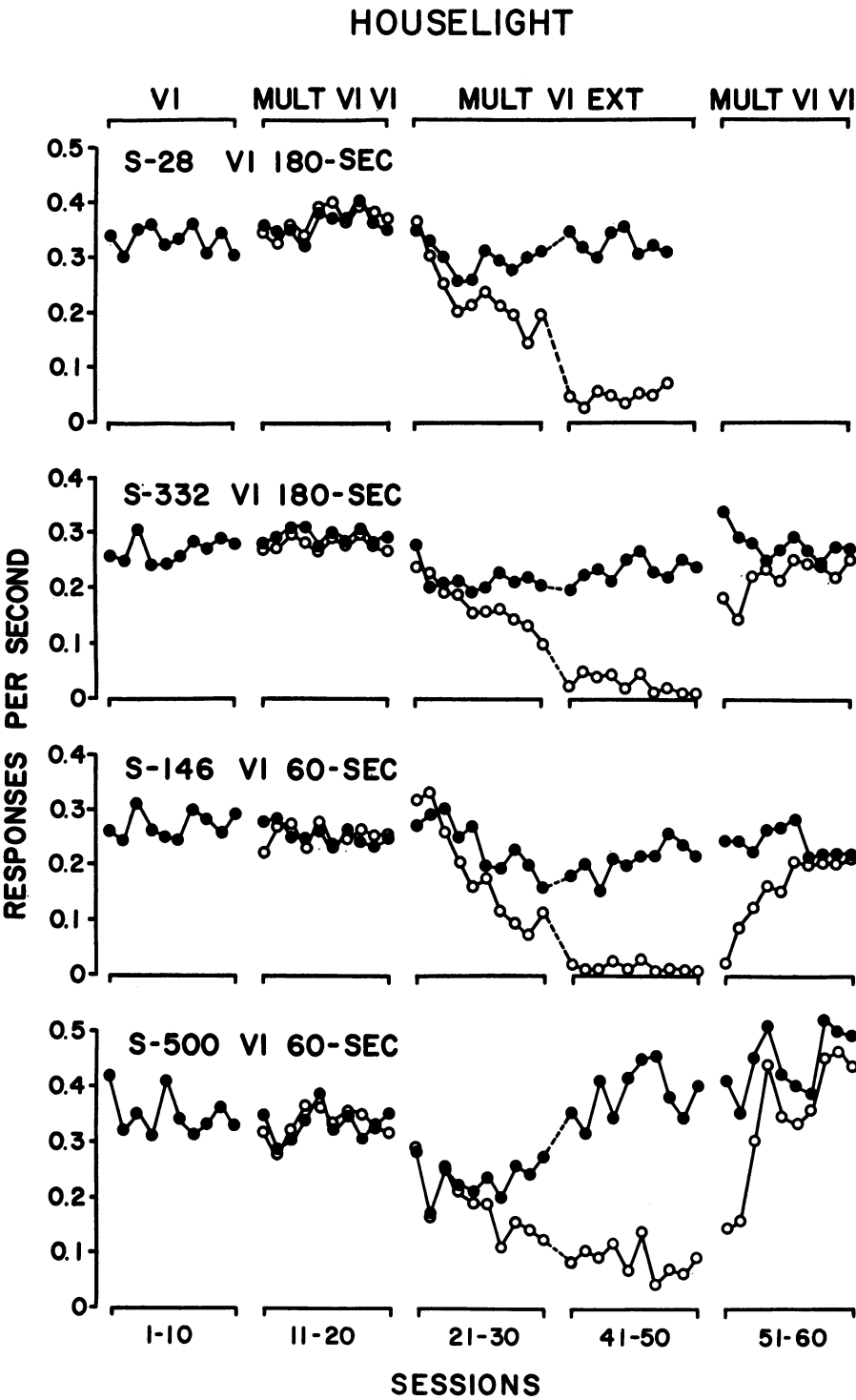
Fig. 1. Changes in overall rate of responding in the unchanged (filled symbols) and changed components (unfilled symbols) under the four conditions of the experiment for individual monkeys. Components were associated with red or green lever lights. The unchanged component schedule was VI 180-sec (S-28, S-332) or VI 60-sec (S-146, S-500). Sessions 1 to 10 refer to the last 10 sessions under the VI schedule in isolation. The first 10 (Sessions 21 to 30) and last 10 sessions under the *mult* VI EXT schedule (Sessions 41 to 50) are separated by dashed lines.

Fig. 2. Changes in overall rate of responding in each component under the four conditions of the experiment for individual monkeys. Components were associated with red or green houselights. Details are as in Figure 1.
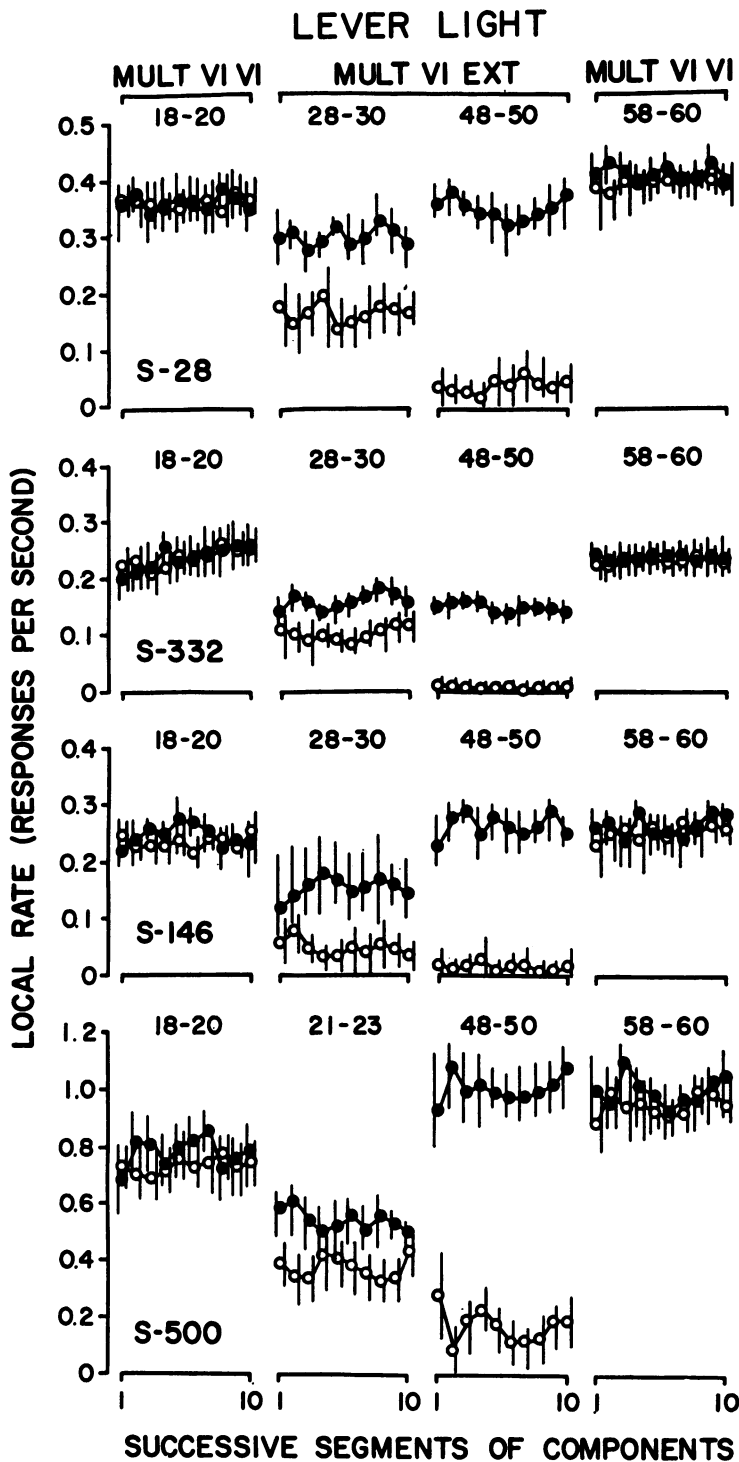
Fig. 3. Changes in local rate of responding within successive segments of the unchanged (filled symbols) and changed components (unfilled symbols) under the *mult* VI VI, *mult* VI EXT, and subsequent *mult* VI VI schedules for individual monkeys. Components were associated with red or green lever lights. The unchanged component schedule was VI 180-sec (S-28, S-332) or VI 60-sec (S-146, S-500). Data are based on means over the three sessions indicated. Vertical lines show ranges.
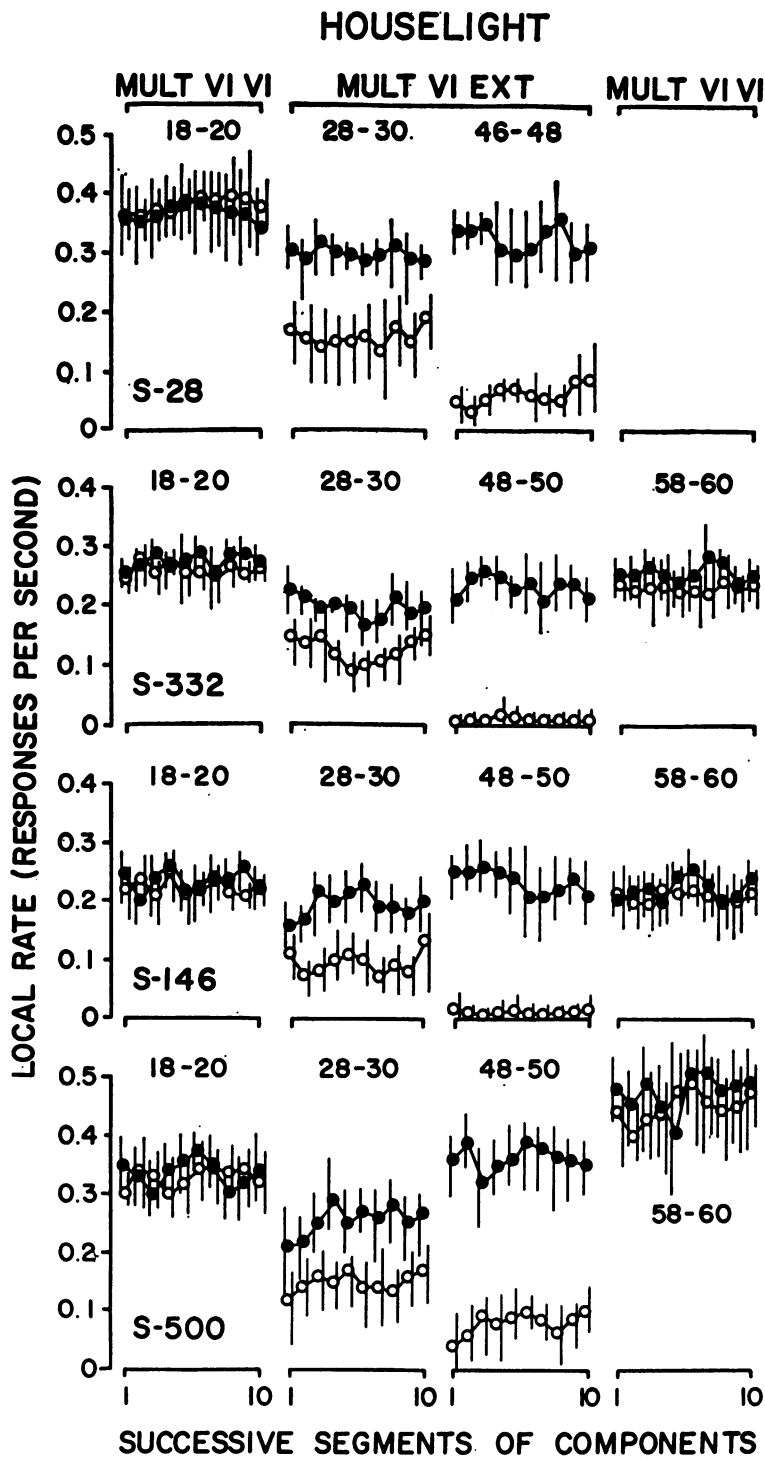
Fig. 4. Changes in local rate of responding within successive segments of each component under the *mult* VI VI, *mult* VI EXT, and subsequent *mult* VI VI schedules for individual monkeys. Components were associated with red or green houselights. Details are as in Figure 3.

monkeys except S-332. Again, the local rate of responding varied unsystematically across successive segments of that component. As in the VI component, no single pattern characterized local responding in the EXT component. When the *mult* VI VI schedule was reinstated (Sessions 58 through 60), the local rate of responding again varied unsystematically across successive segments of each component.

The occurrence of negative induction when component schedules were associated with houselights is not surprising. Negative induction, rather than positive contrast, has been obtained with individual pigeons when key pecking produced food and components were associated with houselights, tones, or lights localized away from the key (*e.g.*, Keller, 1974; Redford and Perkins, 1974; Schwartz, 1975; Schwartz, Hamilton, and Silberberg, 1975; Spealman, 1976), or when treadle pressing, rather than key pecking, produced food (Hemmes, 1973; Westbrook, 1973). Negative induction also has been obtained with individual rats when lever pressing produced food and components were associated with houselights or tones (*e.g.*, Beninger and Kendall, 1975; Freeman, 1971; Gutman, Sutterer, and Brush, 1975; Pear and Wilkie, 1971; White, 1978; Zimmerman and Schuster, 1962).

Negative induction also occurred with squirrel monkeys when the stimuli associated with component schedules were localized on the lever. These results differ from those obtained with pigeons under similar schedules when stimuli were localized on the key. In a study by Spealman and Gollub (1974), for example, positive contrast was obtained with pigeons when as few as 20 (VI 180-sec) or as many as 120 food presentations per hour (VI 30-sec) were scheduled in the VI components, and when average rates of responding under the *mult* VI VI schedules were as low as 0.26 or as high as 1.59 responses per second—values as extreme as those in the present study. Thus, the occurrence of negative induction, rather than positive contrast, with squirrel monkeys cannot be explained easily by the particular frequencies of food presentation or the particular baseline rates of responding maintained in the present study. Whether or not negative induction with squirrel monkeys also occurs at more extreme schedule values or baseline rates of responding awaits direct test.

Negative induction occurred most reliably during initial sessions under the *mult* VI EXT schedule. Because of the "correction" procedure used here, the duration of the EXT components and of sessions were often extended during this period. It is unlikely that these factors were responsible for the failure to obtain positive contrast with squirrel monkeys. Under comparable "correction" procedures with pigeons, a large positive contrast effect (peak contrast; *cf.* Bloomfield, 1966; Terrace, 1966a) is usually observed. Moreover, positive contrast failed to develop in the present study even when responding in the EXT component declined to near zero, and the durations of the EXT components and of sessions were no longer extended.

EXPERIMENT II

In Experiment I, negative induction was observed reliably while responding declined in the EXT component, but was not always observed after extended exposure to the *mult* VI EXT schedule. This finding suggests that the occurrence of negative induction depended on a gradual decline of responding during extinction. Experiment II examined whether or not negative induction would also occur when responding declined abruptly in the absence of food presentation. Squirrel monkeys were exposed to a sequence of VI and multiple variable-interval timeout schedules of food presentation. Under the latter schedule, the VI component was associated with either a localized (lever light) or a diffuse visual stimulus (houselight); the timeout component was associated with darkness. Timeout rather than EXT components were used to maximize the possibility that responding would decline abruptly in the absence of food presentation (*cf.* Reynolds, 1961; Sadowsky, 1973).

METHOD

Subjects and Apparatus

Three mature male squirrel monkeys, weighing 720 to 900 g when allowed free access to food and water, were maintained at about 80% of their free-feeding weights, and were fed and housed as described previously. Monkey S-332 had served in Experiment I. Monkeys S-153 and S-154 were experimentally naive at the beginning of the

study. The apparatus was the same as in Experiment I.

Procedure

After preliminary training, each monkey was exposed to the VI 60-sec schedule of food presentation used in Experiment I. The VI schedule was associated with either the red lever light (S-153) or the red houselight (S-154, S-332). When responding stabilized (18 to 31 sessions), the schedule was changed to multiple variable-interval timeout. This schedule was identical to the *mult* VI 60-sec EXT schedule used in Experiment I except that all lights were extinguished during the timeout component. After 10 (S-153, S-332) or 30 sessions (S-154), the sequence of schedules (variable-interval, multiple variable-interval timeout) was repeated. In this second sequence, the VI component was associated with either the red houselight (S-153) or the red lever light (S-154, S-332). The VI schedule was in effect for 16 to 21 sessions, and the multiple variable-interval timeout schedule was in effect for 10 sessions.

RESULTS AND DISCUSSION

Figures 5 and 6 show changes in the overall rate of responding in each component when the VI schedule was changed to multiple variable-interval timeout for individual monkeys. The VI component was associated with either the red lever light (Figure 5) or the red houselight (Figure 6). When the multiple variable-interval timeout schedule was introduced, responding in the timeout component declined abruptly for S-153 and S-332 under both the lever light and houselight conditions; responding also declined abruptly for S-154 under the lever-light condition. In each of these cases, responding in the VI component was affected unsystematically by the schedule change; neither negative induction nor positive contrast was observed. For S-154 (houselight condition), however, responding in each component declined gradually when the VI schedule was changed to multiple variable-interval timeout (negative induction). Hence, negative induction was correlated with a gradual rather than abrupt decline of responding in the timeout component.

These results suggest that the gradual decline of responding in the absence of food
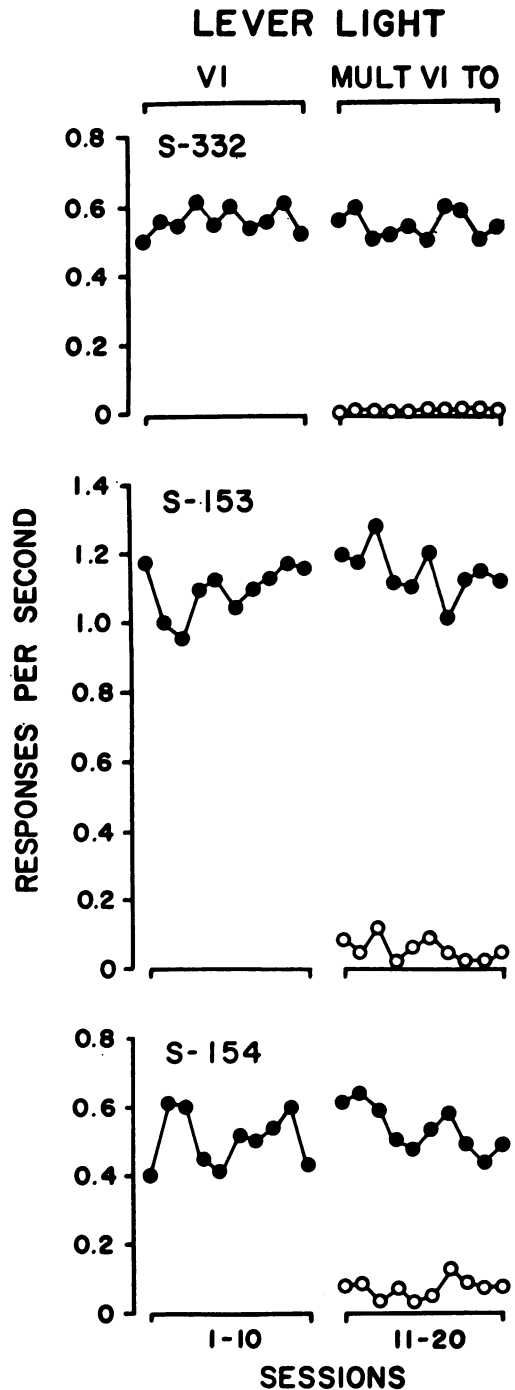

Fig. 5. Changes in overall rate of responding under the VI and multiple variable-interval timeout schedules for individual monkeys. The VI 60-sec schedule (filled symbols) was associated with the red lever light, and timeout (unfilled symbols) with darkness. Sessions 1 to 10 refer to the last 10 sessions under the VI schedule in isolation.
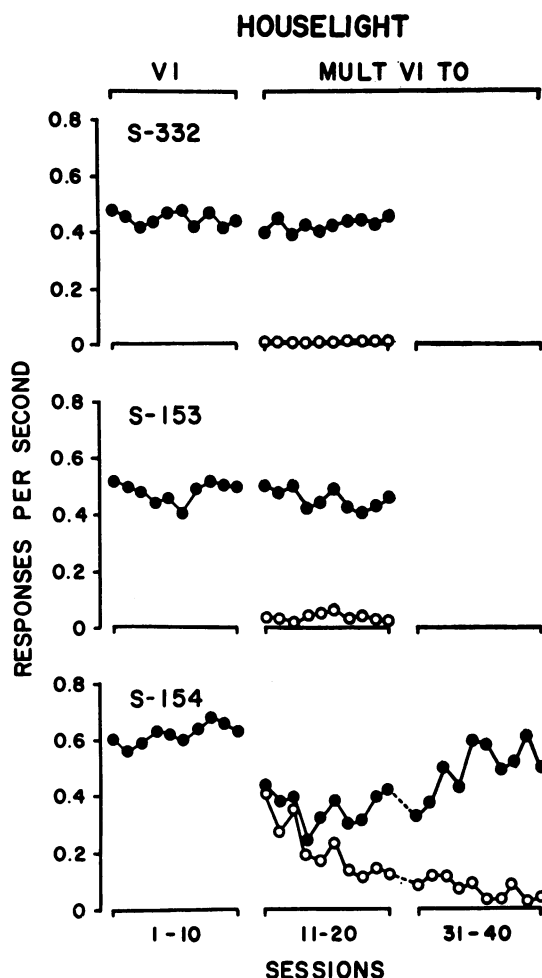
HOUSELIGHT

Fig. 6. Changes in overall rate of responding under the VI and multiple variable-interval timeout schedules for individual monkeys. The VI schedule was associated with the red houselight, and timeout with darkness. The first 10 (Sessions 11 to 20) and last 10 sessions under the multiple variable-interval timeout schedule (Sessions 31 to 40) are separated by dashed lines for Monkey S-154. Other details are as in Figure 5.

presentation was necessary for the occurrence of negative induction here. Terrace (*e.g.*, 1963, 1966*b*, 1972) has offered a similar account of positive contrast based on discrimination learning with and without "errors" (responding in the absence of food presentation). It should be noted, however, that positive contrast often has been reported when key pecking by pigeons declined abruptly in a component associated with the absence of food presentation (*e.g.*, Halliday and Boakes, 1974; Kodera and Rilling, 1976; Sadowsky,

1973; Vieth and Rilling, 1972). While a gradual decline in responding in the absence of food presentation may be necessary for the development of negative induction, it does not appear to be critical for the development of positive contrast.

GENERAL DISCUSSION

Negative induction was observed with squirrel monkeys under conditions similar to those that produce positive contrast with pigeons. These results are not reconciled easily with theoretical accounts of multiple-schedule interactions that either explicitly or implicitly treat positive contrast as a ubiquitous phenomenon (*e.g.*, Bloomfield, 1969; Catania, 1973; Herrnstein, 1970; Reynolds, 1961; Terrace, 1972). On cursory examination, the present results also appear difficult to reconcile with an "additivity" account of contrast (*cf.* Schwartz and Gamzu, 1977); negative induction rather than positive contrast was obtained when visual stimuli associated with component schedules were localized on the lever. However, according to this account, positive contrast is expected only when (1) responding is maintained by a contingency between stimulus and reinforcer and (2) such responding is directed to and operates the manipulandum on which responses produce food. While the contingency between stimulus and reinforcer can in some cases facilitate the acquisition of manipulandum-directed responding by squirrel monkeys, this effect is strikingly weak (Gamzu and Schwam, 1974, Experiment 1). Moreover, the contingency between stimulus and reinforcer appears to be ineffective in subsequently maintaining directed responding (Gamzu and Schwam, 1974, Experiment 2). Hence, the failure to obtain positive contrast with squirrel monkeys is neither unexpected nor incompatible with an account of positive contrast based on responding maintained by stimulus-reinforcer and response-reinforcer contingencies. In the absence of manipulandum-directed responding maintained by the former contingency, negative induction, rather than positive contrast, may be the rule.

To date, the majority of studies concerned with multiple-schedule interactions have dealt exclusively with positive contrast, and usually with pigeons. The present results suggest that

the nature of interactions in multiple schedules may differ qualitatively in different species. Future research is required to establish the species generality of both contrast and induction. Such research seems necessary for a comprehensive account of interactions in multiple schedules.

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